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FINAL REPORT

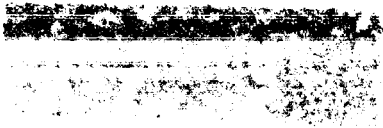
METAL EXPULSION DIAPHRAGM DEVELOPMENT
FOR SPHERICAL PROPELLANT TANKS

Contract No. 950243 with
California Institute of Technology
Jet Propulsion Laboratory

(SUBCONTRACT UNDER NASA CONTRACT NAS7-100)

12 December 1962

HONEYWELL *Aeronautical Division*



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Prepared by:

Mario William Cardullo
Senior Development Engineer

Approved by :

B. E. Harms /for
R. E. Michel
Staff Engineer
Reaction Control Systems

H. W. Boudreau
H. W. Boudreau
Section Head

Minneapolis-Honeywell Regulator Company
Aeronautical Division
Minneapolis, Minnesota

CR-50,846

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FOREWORD

This report has been prepared by Minneapolis-Honeywell Aeronautical Division's reaction control group under JPL Contract 950243, Metal Expulsion Diaphragm Development for Spherical Propellant Tanks.

Special acknowledgement is given to Mr. Don Beadles, Honeywell Ordnance Division for his assistance in the explosive forming phase of fabrication and Mr. Don Tome, Aero model shop for his assistance in the diaphragm fabrication.

SECTION I SUMMARY

This report describes Honeywell's work conducted under Contract No. 950243 issued by the Jet Propulsion Laboratory of the California Institute of Technology, for design and development of an 18-inch metal expulsion diaphragm for spherical propellant tanks.

The fabrication of the 18-inch diaphragm has followed an evolutionary process. The final process chosen for forming these diaphragms consisted of:

- Using 0.030 inch aluminum (1100 - 0)
- Preforming by means of air pressure down to within one-half to one-fourth inch of the final form
- Annealing the aluminum
- Explosive forming into final hemispherical shape
- Chemical milling of the aluminum to the required thickness
- Convoluting

Ten of the convoluted diaphragms were tested with water. Units evaluated were of 0.010 and 0.015 inch thickness.

Tests conducted on both sizes indicated that over 90 per cent of the volume above the diaphragm would be expelled with a differential pressure of less than four psi. However, expulsion efficiency over 98 per cent required upwards of 25 psi. Two diaphragms were subjected to a high pressure differential to obtain complete expulsion in less than 30 seconds. Both units performed satisfactorily.

Results of this program indicate that the fabrication method evolved would be applicable to a wide range of diaphragm sizes. However, development of a method for reducing the pressure needed to achieve 98 to 99 per cent expulsion efficiency is still required.

A continuous weekly log account of the program and its accomplishments is contained in Appendix A.

SECTION II INTRODUCTION

GENERAL

Under the influence of zero gravity conditions or randomly oriented acceleration forces, a means of positive expulsion must be provided for liquid propellants.

Positive expulsion can be obtained in several ways using bladders, pistons, diaphragms, or bellows. The energy required for expulsion can come from a stored gas, gas generant, or a gravitational field produced by rotation of the vehicle.

Bladders and pistons have previously been used extensively, but both pose serious problems for operation in a space environment. In general, bladders have been made of elastomeric materials. A disadvantage of elastomeric bladder systems is its limited life in contrast with storable propellants.

HONEYWELL'S APPROACH

Honeywell's approach to positive propellant expulsion in space uses a double convoluted aluminum diaphragm, see Figure 1. A spherical expulsion unit has the following advantages:

- The circumferential corrugations or convolutions can be designed so the equivalent length fits the inside contour of the other shell. Stretching or elongation of the diaphragm is minimized.

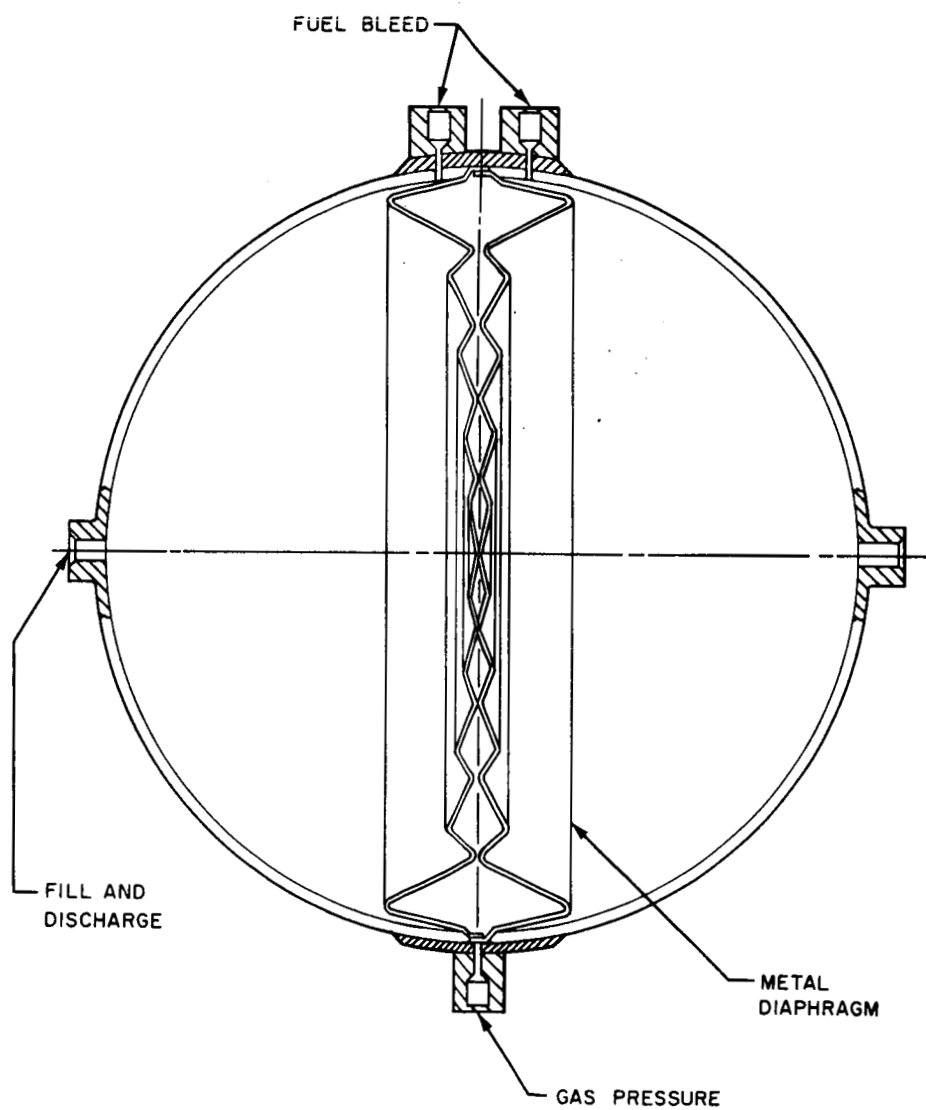


Figure 1. Double Convoluted Diaphragm Configuration

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- Pressurizing gas is introduced between the diaphragm. Resulting deflections tend to minimize creases or folds in the surfaces.
- The two halves of the convoluted diaphragms can be welded and assembled as a unit. This process constitutes a preformed or prefolded bladder.
- A nesting technique could be used to reduce the ullage to below 2.5 per cent for an 18-inch diameter tank.
- Each of the two halves or volumes of the configuration can be used for a bipropellant system within a single tank geometry.

The tank can only be fully expelled once. However, several partial expulsions can be made.

SECTION III PROGRAM

OBJECTIVES

This program was directed toward developing and fabricating an 18-inch diameter metal expulsion diaphragm. The material chosen had to be compatible and impervious with hydrazine, nitrogen tetroxide, and pressurizing gas which is the output of a hydrazine monopropellant gas generator. The diaphragm would have to be compatible with these substances during a one year storage time in a space environment. The unit would have to be capable of 98 to 99 per cent expulsion efficiency.

PLAN

To achieve the previously described program objectives, a Honeywell developmental program consisting of the following phases was chosen:

- Material study
- Fabrication development
- Evaluation
- Fabrication and delivery

Material Study

Material study results revealed that the following types of materials could be used for both propellants:* (Reference 1)

*Class 1 materials--Corrosion rate of less than 1 mil per year.

Reference 1: "Compatibility of Rocket Propellants With Materials of Construction" DMIC Memo 60, 15 September 1960.

- Aluminum alloys (1100, 2024, 6061)
- 304 Stainless Steel
- Titanium alloy 6Al-4V

For ease of fabrication, Honeywell used aluminum alloys. Prior to initiating the fabrication of the 18-inch unit, a material test was performed to determine the suitability of various aluminum alloys. Test samples were placed in a boiling solution of 65 per cent nitric acid for five minutes and the change in weight noted. Table 1 contains results of this test.

Based upon the results of this test and fabrication considerations, Honeywell decided to investigate 1100 and 6061 aluminum alloys.

Fabrication Development

Fabrication of the 18-inch diameter diaphragm followed an evolutionary process. The original 3-inch proof-of-principle unit was drawn in one step using a male punch and a draw ring. This unit was convoluted by using the punch.

Initially, a method similar to the one used for the 3-inch unit was tried for the 18-inch diaphragm. An 18-inch diameter punch and two draw rings were made from tempered masonite. Using this punch and these draw rings, the first units were only drawn down several inches before serious wrinkles formed in the material.

Next, an oil bath beneath the aluminum blank was employed. When this process was tried, rippling occurred almost immediately. An air draw process was next used to preform the blanks. In this process, the material was clamped between the ring dies and a pressure plate. Air pressure was

Table 1. Compatibility of Aluminum**

Type	Per Cent Weight Loss
3003-H14	1.4
6061-0	0.9
5052-0	1.0
1100-0	1.1

* Samples submerged for five minutes in a boiling solution of 65 per cent nitric acid.

**Test suggested by Battele Memorial Institute for a comparison of materials for use with nitrogen tetroxide.

then employed to form the hemisphere. Using this air draw process, rippling still occurred. An explosive forming method was tried using only the ring die and a bottom tank. This was unsuccessful. A female die was then made using the male punch as the form. The female die was made by laying up layers of fiber glass in the male form with epoxy. Vacuum holes were incorporated into this die. The die was then backed up with reinforced concrete.

The final Honeywell process for forming these diaphragms consisted of:

- Using 0.030-inch aluminum (1100-0)* in combination with polyethylene and Lubri-plate.
- Preforming by means of air pressure to within one-half to one-fourth inch of the final form. Table 2 presents data for the air draw process prior to explosive forming.
- Annealing the aluminum.
- Explosive forming into the final hemispherical shape. Table 3 presents explosive forming data.
- Chemical milling the aluminum to the required thickness.
- Convoluting -- However, convoluting of the diaphragms initially posed certain problems. Initially, the male punch was used to form the convolutions. However, it was found that the diameter of the punch had to be appreciably reduced to form the first convolution. Support rings were also necessary. Using this method, it was possible to form the required convolutions. However, the first diaphragms showed wrinkled flanges and rippling of the center convolution. These minor problems were solved by an ironing process.

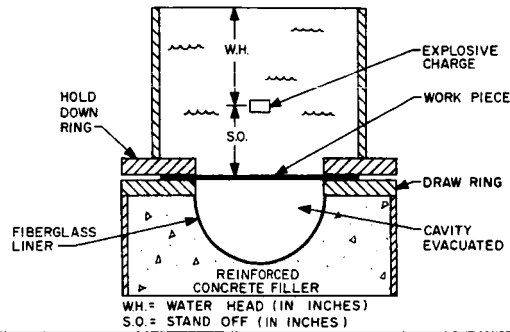
*6061 did not prove successful during the forming operation.

Table 2. Air Draw Pressure Data

Material Thickness	Pressures (psig)	Depth of Draw	Size of Exp. Charge	Results
0.030	64 lbs.	5"		
0.040	110	6 1/2"		
0.040	120	7 1/2"	6"	Orange peel-not deep enough on air draw
0.040	138	7 1/4"		Leak developed in top plate seal
0.040	127	8 7/8"	3"	Good
0.030	96	8 1/2"	3 + 1 1/2"	Two charges to iron out
0.030	96	8 1/2"		Good
0.030	96	8 1/2"		Pulled out-excessive lube
0.030	96			Pulled out-excessive lube
0.030	96			Fracture
0.030 + 0.020	75			Fracture
0.030	88			Fracture
0.020 + 0.030	138	7 1/4"		Orange peel on 0.020
0.030	92	8 3/4"		
0.020	60			
0.030	92			Broke
0.030	88			Broke
0.030	92	8 3/4"		Good
0.030	92	8 3/4"		Good
0.030	92	8 3/4"	Seconds	Broke
0.030	92	8 1/4"	35	Good
0.030	94	8	50	Good
0.030	96	8 1/2"	50	Good
0.030	96	7 3/4"	60	Good-pulled one side
0.030	96	7 3/4"	60	Pulled to one side

*All 1100-0 Aluminum

Table 3. Explosive Forming Data



Date	Shot No.	Blank	Alloy	S. O.	W. H.	Charge	Remarks
5-18-62	1	0.020 x 24" Dia Alum	1100	9	9	Circular 6" 40 GR	Drew 3" Some wrinkling
5-18-62	1A	Same Blank		9	12	Circular 18" 40 GR	Damaged by reflective waves
5-18-62	1B	Same Blank		7	15	Circular 36" 50 GR	Pulled loose from masonite draw ring
5-18-62	2	0.020 x 24" Dia Alum	1100	7	11	Circular 36" 50 GR	Drew 8" then fractured
5-18-62	3	0.020 x 24" Dia Alum	1100	10	8	Circular 36" 50 GR	Fractured - Damaged by reflective waves
5-18-62	4	0.020 x 24" Dia Alum	1100	10	8	Circular 24" 50 GR	Pulled loose from draw ring Drew approximately 8"
5-18-62	5	0.020 Preform Drawn to 5 1/2" not annealed	1100	7	16 1/2	Circular 9" 40 GR	Fractured
5-18-62	6	0.020 Preform Drawn to 5 1/2" not annealed	6061-0	7	16 1/2	Circular 9" 40 GR	Fractured
At this point, we felt it was necessary to make a cavity so that we could draw a vacuum and improve the draw ring and hold down assembly.							
6-12-62	7	0.020 Preform Drawn to 5 1/2" and annealed	6061	9	14 1/2	Circular 9" 40 GR	Sheared around circumference
6-13-62	8	0.020 Preform Drawn to 6 1/2" and annealed	1100	12	12 1/2	7" 40 GR	Fractured - large "orange peel" area
6-13-62	9	0.020 Preform Drawn to 5 1/2" and annealed	1100	12	11 1/2	3 1/2" 40 GR	Fractured - large "orange peel" area
6-13-62	10	0.020 Preform Drawn to 5 1/2" and annealed	1100	12	11 1/2	1 1/2" 40 GR	Drew to 7 1/2"
6-13-62	10A	Same Preform		9	16 1/2	1" 40 GR	Fractured around perimeter
6-14-62	11	0.020 Preform Drawn 5" deep and Annealed	1100	10	13	1 1/2" 40GR	Drew to 6 1/2" - No Orange Peel
6-14-62	11A	Same Blank		10	14 1/2	1 1/2" 40GR	Drew to 7"
6-14-62	11B	Same Blank		10	15	1 1/2" 40GR	Fractured Through Center
6-14-62	12	0.020 Preform Drawn 8" deep	1100	10	16	1 1/2" 40GR	Drew to Bottom - Some Wrinkling
6-14-62	13	0.020 Preform Drawn 4 1/2" deep	1100	10	12 1/2	1 1/2" 40GR	Drew to 5 5/8"
6-14-62	13A	Same Blank		10	13 1/2	1 1/2" 40GR	Drew to 6 3/4" { At this point, we put shims between rings to allow more draw.

Table 3. (Continued)

Date	Shot No.	Blank	Alloy	S.O.	W.H.	Charge	Remarks
6-14-62	13B	Same Blank		10	13 1/2	1 1/2" 40 GR	Fractured around circumference - drew to 7 1/8"
6-14-62	14	0.020 x 28" Dia Alum	1100	10	8	12" 40 GR	Drew to 6"
6-14-62	14A	Same Blank		10	14	1 1/2" 40 GR	Fractured
6-15-62		Re-worked Die to Put 1/8 R. on draw ring					(Was approximately 1/16")
6-15-62	15	0.020 x 28" Dia Alum	1100	10	8	16" 40 GR	Fractured badly
6-15-62	16	0.020 Preform Drawn to 6" and annealed	6061	10"	14	Circular 6" 40 GR	Drew to 7"
6-15-62	16A	Same Blank		10	15	6 pcs, 40 GR 1 1/2" long	Fractured badly
6-15-62	17	0.030 x 28" Dia Alum	1100	10	8	10 pcs 40 GR 1 1/2" long	Drew to 5 1/2"
6-18-62	18	0.020 x 28" Dia Alum	1100	10	8	10 pcs 40 GR 1 1/2" long	Fractured
6-18-62	19	0.020 x 28" Dia Alum	1100	10	8	8 pcs 40 GR 1 1/2" long	Drew to 6"
6-18-62	20	0.020 x 28" Dia Alum	1100	10	8	8 pcs 40 GR 1 1/2" long	Fractured (appeared to have vacuum leak)
6-19-62	17A	0.030 Preform from 6-15 (annealed)	1100	10	13 1/2	4 pcs 40 GR 1/2" long	Drew to 6"
6-19-62	17B	Same Blank		10	14	3 pcs 40 GR 1" long	Fractured at perimeter
6-20-62		Increased draw radius to 3/10" and tried air draw.					
6-21-62	21	0.030 Preform Drawn to 3" deep	1100	10	8	8 pcs 40 GR 1 1/2" long	Drew to 5 1/2"
6-22-62	22	0.030 Preform Draw to 6" and annealed	1100	10	8	8 pcs 40 GR 1" long	Drew to 7 1/4"
6-22-62	22A	Same Blank		12	8	8 pcs 40 GR 1" long	Drew to 8"
6-22-62	22B	Same Blank		12	8	8 pcs 40 GR 1" long	Fractured in 3-way pattern
6-22-62	23	0.030 Preform Drawn to 6 1/2"	1100	14	8	8 pcs 40 GR 1" long	Drew nice to 8"
6-22-62	23A	Same Blank		14	8	8 pcs 40 GR 1" long	Drew nearly to bottom - Some wrinkles
6-22-62	23B	Same Blank		9	8	4 pcs 40 GR 1" long	Formed good, but considerable "orange peel"
6-22-62	24	0.030 Preform Drawn to 6 1/2" and annealed	1100	14	8	8 pcs 40 GR 1" long	Drew to 7 1/2 but 4 pcs failed to detonate
6-22-62	24A	Same Blank		12	8	8 pcs 40 GR 1" long	Drew to 8 1/4"
6-22-62	24B	Same Blank		10	8	6 pcs 40 GR 1" long	Drew to size - some "orange peel" and wrinkles from excessive grease
6-26-62	25	Preform Drawn to 6 1/2" and annealed	1100	14	8	8 pcs 40 GR 1" long	Drew to 8 1/4" - 1 wrinkle (0.030 blank)
6-26-62	25A	Same Blank		14	8	8 pcs 40 GR 1" long	Drew nearly to depth - wrinkle worse
6-26-62	25B	Same Blank		9	8	4 pcs 40 GR 1" long	Fair part - helped wrinkle some by lowering standoff (S.O.)
6-26-62		Tried reversing a completed piece (0.030) by air. Did not reverse uniformly.					

Table 3. (Continued)

Date	Shot No.	Blank	Alloy	S.O.	W.H.	Charge	Remarks
6-27-62	26	0.030 Preform Drawn to 6 1/2" and annealed	1100	13	8	8 pcs 40 GR 1" long	Drew to 8 1/2" - 1 bad wrinkle
6-27-62	26A	Same Blank		9	8	8 pcs 40 GR 1" long	Drew to size but wrinkle stayed
6-27-62	27	0.030 Preform Drawn to 5 1/2" and annealed	1100	12	8	7 pcs 40 GR 1" long	Drew to 7"
6-27-62	27A	Same Blank		12	8	8 pcs 40 GR 1" long	Drew to 7 1/2" - Some wrinkling
6-27-62	27B	Same Blank		10	8	8 pcs 40 GR 1" long	Drew to 8 1/2" - considerable "orange peel"
6-27-62	27C	Same Blank		9	8	6 pcs 40 GR 1" long	Fractured
6-27-62	28	0.020 Preform Drawn to 5 1/4" and annealed	6061	12	8	9 pcs 40 GR 1" long	Drew to 7 1/4" - 1 wrinkle
6-27-62	28A	Same Blank		10	8	8 pcs 40 GR 1" long	Drew to 8 1/4" Reduced wrinkle
6-27-62	28B	Same Blank		10	8	7 pcs 40 GR 1" long	Fractured
New Draw Ring and Air Draw Cover made by Gillitzer during shutdown							
7-18-62	29	0.020 Preform Drawn to 6 3/4" and annealed	1100	6	8	6 pcs 40 GR 1" long	Fractured (Demonstration shot for Howard Stanford of JPL)
8-9-62	30	0.040 Preform Drawn to 7 1/2" and annealed	1100	6	8	6 pcs 40 GR 1" long	Drew all the way, but "orange peeled"
8-9-62	31	0.040 Preform	1100	6	8	3 pcs 40 GR 1" long	Good part - no "orange peel"
8-13-62	32	0.030 Preform Drawn and annealed	8 1/2"	6	8	1 1/2" 40 GR	Drew to 8 7/8" - no "orange peel"
8-13-62	32A	Same Blank	1100	6	8	3 pcs 40 GR 1" long	Good part, but material extruded into vacuum holes
8-13-62	33	0.030 Preform Drawn to 8 1/2" and annealed	1100	9	8	3 pcs 40 GR 1" long	Good hemisphere
9-6-62	34	Sandwich of (2) 0.020 blanks and (1) 0.010 in between	1100	12	8	26 pcs 100 GR 1 1/2" each and 1 pg. 100 GR 1"	Drew to 3 1/2". Appeared to have air between blanks Drew too much from one side, and wrinkled - ruined tank
9-7-62	Made new water tank and started work on chemical process.						
9-8-62	35	2 blanks 0.020 x 28" Dia together	6061-0	9	12	12" 40 GR	Drew to 4 3/4" - Some wrinkling
9-8-62	35A	Same Blanks	6061-0	9	12	13 pcs 40 GR 1"	Drew to 6 1/2"
9-8-62	35B	Same Blanks	6061-0	9	12	13 pcs 40 GR 1"	Broke in Center
9-8-62	36	2 Blanks 0.020 x 28" Dia together	6061	9	12	15 pcs 40 GR 1" long	Drew to 5 1/8" - little wrinkling
9-8-62	36A	2 Blanks 0.020 x 28" Dia together	6061	9	12	15 pcs 40 GR 1" long	Drew to 6 3/4"
9-11-62	37	2 Blanks 0.030 x 28" Dia together	1100	9	12	15 pcs 40 GR 1 1/2" long	Drew to 5"
9-11-62	37A	2 Blanks 0.030 x 28" Dia together	1100	9	12	15 pcs 40 GR 1 1/2" long	Drew to 5 3/4", but very one sided
9-11-62	38	0.040 Alum x 28" Dia	1100	9	12	15 pcs 40 GR 1 1/2" long	Drew to 6 3/8"
9-11-62	38A	0.040 Alum 6 3/8" deep	1100	6	12	8 pcs 40 GR 1 1/2" long	Pulled loose from draw ring

Table 3. (Continued)

Date	Shot No.	Blank	Alloy	S.O.	W.H.	Charge	Remarks
9-24-62		At this point, we concentrated on the air draw using various holding techniques and lubricants. On approximately 9-20, we found the answer to our lubricant problem. A sheet of polyethylene film on either side of the blank is an excellent lubricant.					
		Chemical milling operation moved along well under direction of Harry Moore and Don Tome.					
		Air drawing with polyethylene film moved along very well, but due to pressure (approximately 90-92 p.s.i. on 0.030 blanks) we developed some leaks in cavity around cover and in vacuum lines. Convoluting was done at Aero with intermediate anneals at 502.					
10-16-62	39	0.030 Preform Drawn to 8 1/2" and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part
10-16-62	40	0.030 Preform Drawn to 8 1/4" deep	1100	9	12	3 pcs 40 GR 1" long	Good part, 1 wrinkle
10-16-62	41	0.030 Preform Drawn to 8 3/4" deep and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part
10-16-62	42	0.030 Preform Drawn 7 3/4"	1100	9	12	3 pcs 40 GR 1" long	Good part, but slight "orange peel"
10-16-62	43	0.030 Preform Drawn to 8 1/2" and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part
10-16-62	44	0.030 Preform Drawn 8 3/4" and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part
10-16-62	45	0.030 Preform Drawn to 8 5/8" and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part, 1 wrinkle
10-16-62	46	0.030 Preform Drawn to 8 7/8" and annealed	1100	9	12	3 pcs 40 GR 1" long	Good part
10-19-62		Leaks in vacuum lines repaired by Don Tome and Ted Smith.					

Figure 2 shows Honeywell's process for the fabrication of the 18-inch diameter diaphragm.

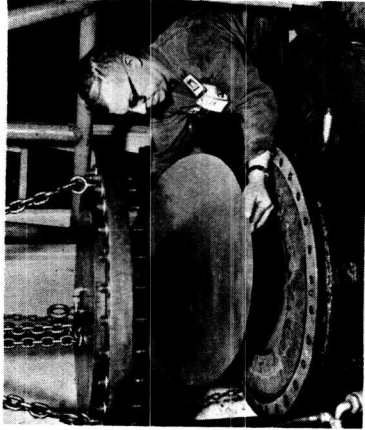
Evaluation

Tests were performed on 10 diaphragms using water as the medium with dry nitrogen gas as the pressurant. Four diaphragms were 0.010 inch nominal thickness. The remaining diaphragms were 0.016 inch thick.

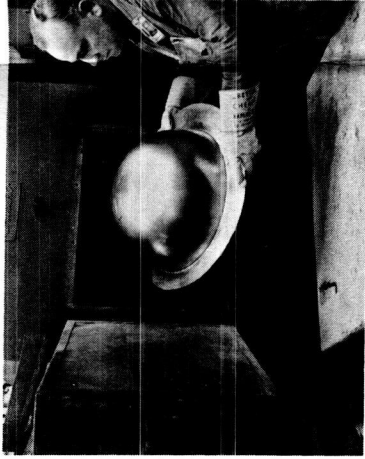
Procedure -- Test diaphragms were placed between a plexi-glass dome and an aluminum base plate, see Figures 3 and 4. Nitrogen was used to expel the water from the unit into a calibrated reservoir tank. Various increments of pressure were applied and the amounts of water expelled were recorded. An exception to this procedure occurred during testing on diaphragms No. 6 and 7. During these tests, a steady pressure was applied to the units to achieve expulsion in less than 30 seconds. Motion pictures (64 frames per second) were taken to record the expulsion progress during these tests.

Results -- Table 4 presents a summary of results. Figures 5 through 12 show the effect of pressure differential upon expulsion.

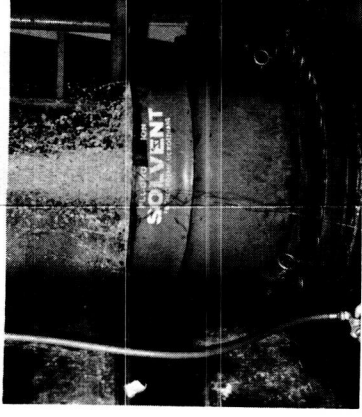
Test diaphragms No. 1, 3, and 9 developed leaks during various phases of expulsion. Test diaphragm No. 1 was originally subjected to 30 per cent expulsion and then drawn back. This caused some serious wrinkling in the unit. A full expulsion was tried next on this unit. When almost all the water had been expelled from the test fixture, tears occurred on the lower portion of the diaphragm stopping the test. During tests with the third diaphragm, small cracks appeared in the lower portion of the unit after 66 per cent of the water was expelled. Similarly, during test with diaphragm No. 9, tears occurred but only after 97 per cent of the fluid had been expelled. These



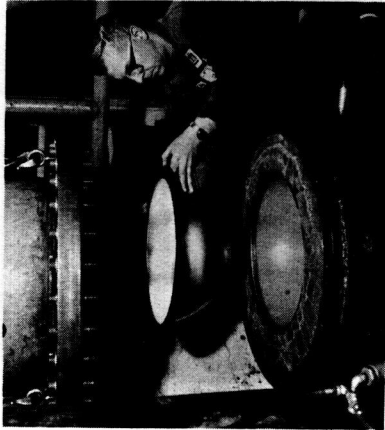
a. 0. 030 Inch Aluminum Blank is Air Drawn to Within One-Half to One-Quarter Inch of Final Size



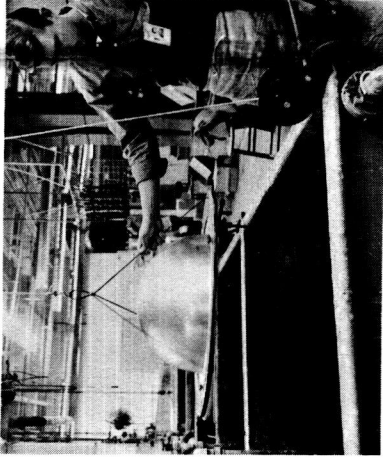
b. Preformed Hemisphere is Annealed



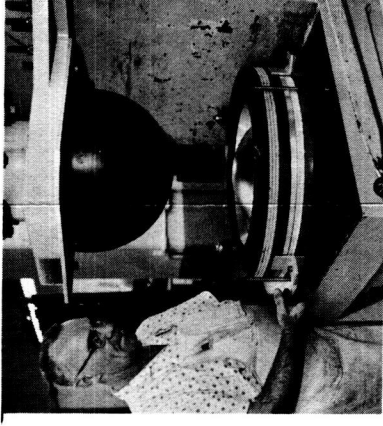
c. Explosive Forming to Final Configuration



d. Finished Hemisphere



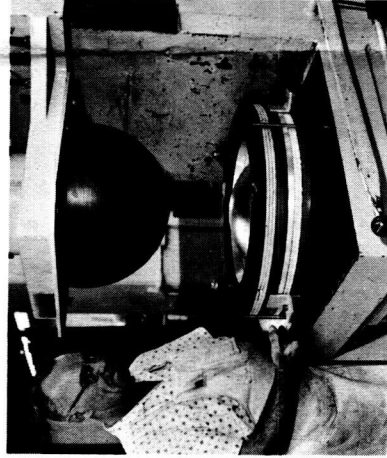
e. Chemical Milling to Required Thickness



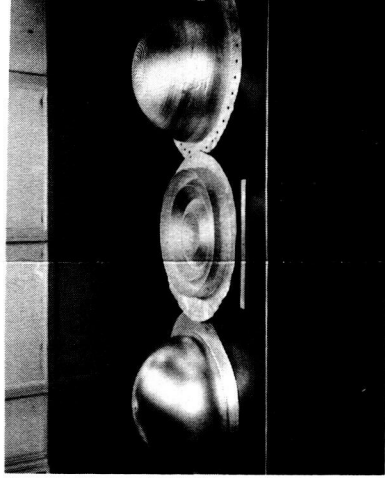
f. Initial Convoluting



g. Interim Anneal



h. Final Convoluting



i. Hemisphere, Convoluted Diaphragm, and Diaphragm After Expulsion

Figure 2. Fabrication of 18-inch Convoluted Diaphragm

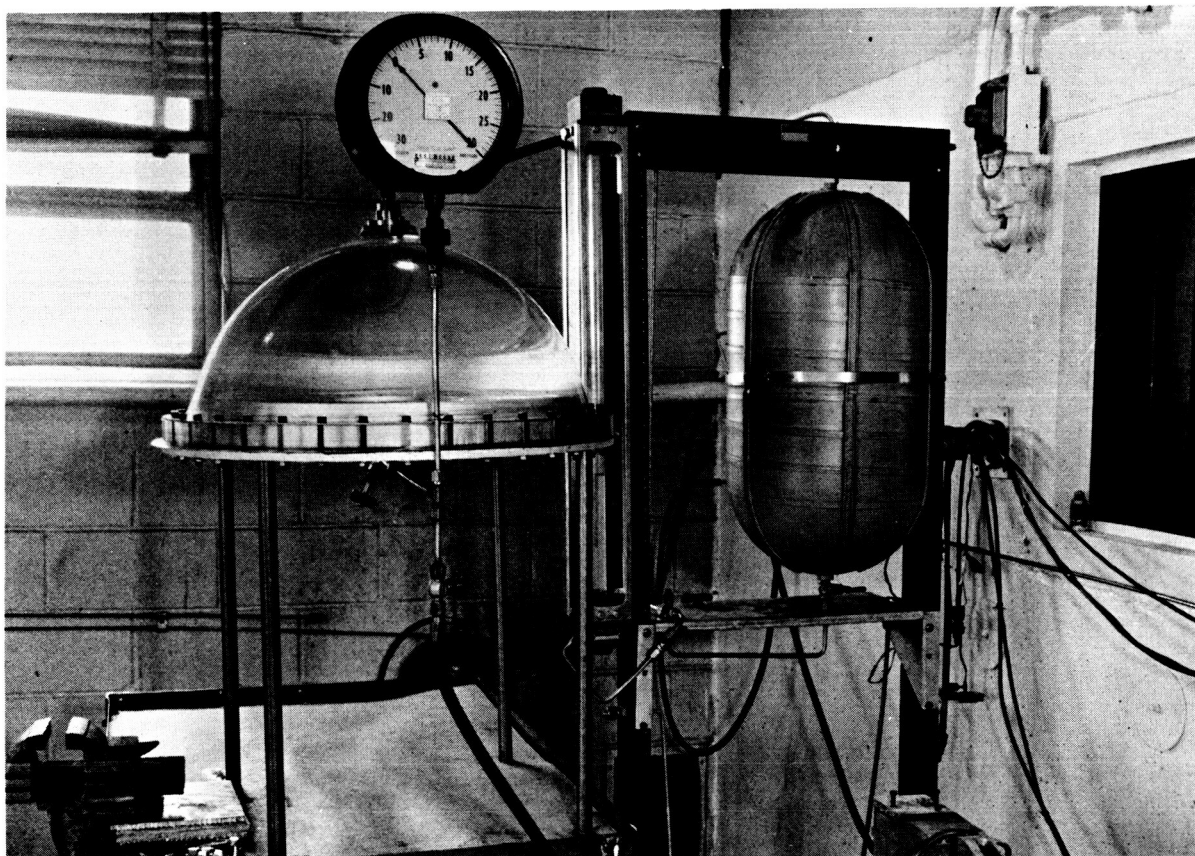
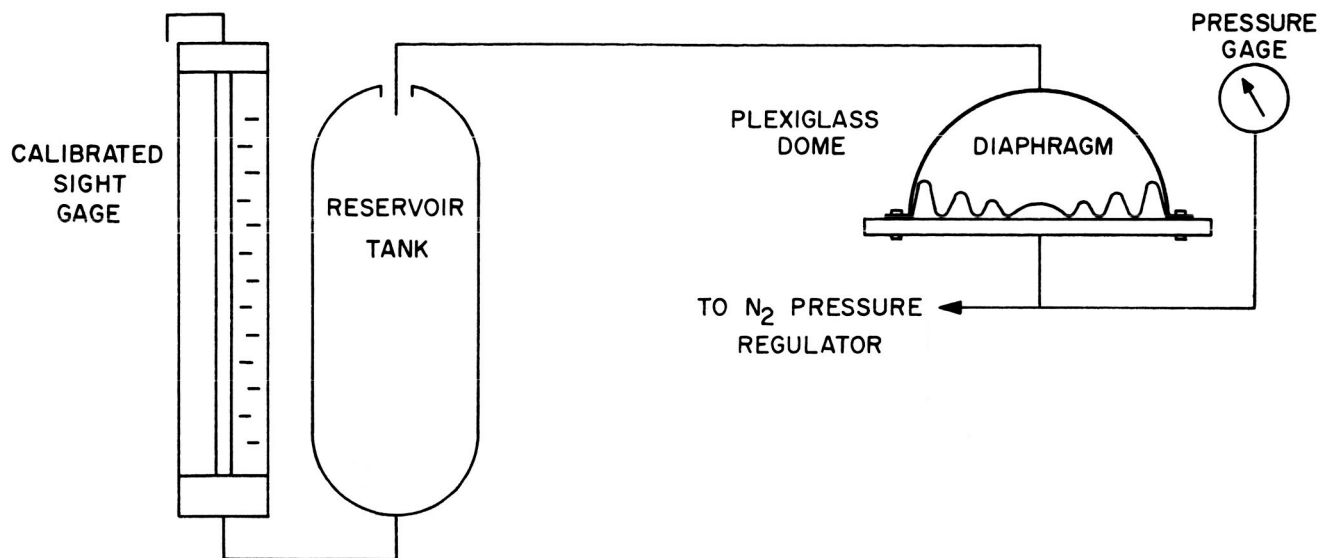


Figure 3. Expulsion Diaphragm Test Set-up

2869-TR1



Figure 4. Diaphragm Mounted in Test Fixture

2869-TR1

Table 4. Results of Expulsion Test Differential Pressure
Required to Expell Water

Diaphragm	Thickness	90 Per Cent	95 Per Cent	98 Per Cent	Expulsion Eff.
		ΔP (psi)	ΔP (psi)	ΔP (psi)	
1	0.010	Original volume not recorded			
2	0.016	2.8	9	25	
3	0.016	Leak developed at 66 per cent			
4	0.010	1.5	2	---	
5	0.010	2.0	4	---	
6**	0.16	High speed expulsion test 15-18 psi			
7**	0.016	High speed expulsion test 25 psi			
8	0.016	2.8	8	22	
9	0.012	1.2	2	9 (Ruptured at 97 per cent)	
10	0.016	2.5	Only reached 94 per cent		

*1100-0 aluminum

**Results of test 6 and 7 are available on 16 mm motion picture film.

2869-TR1

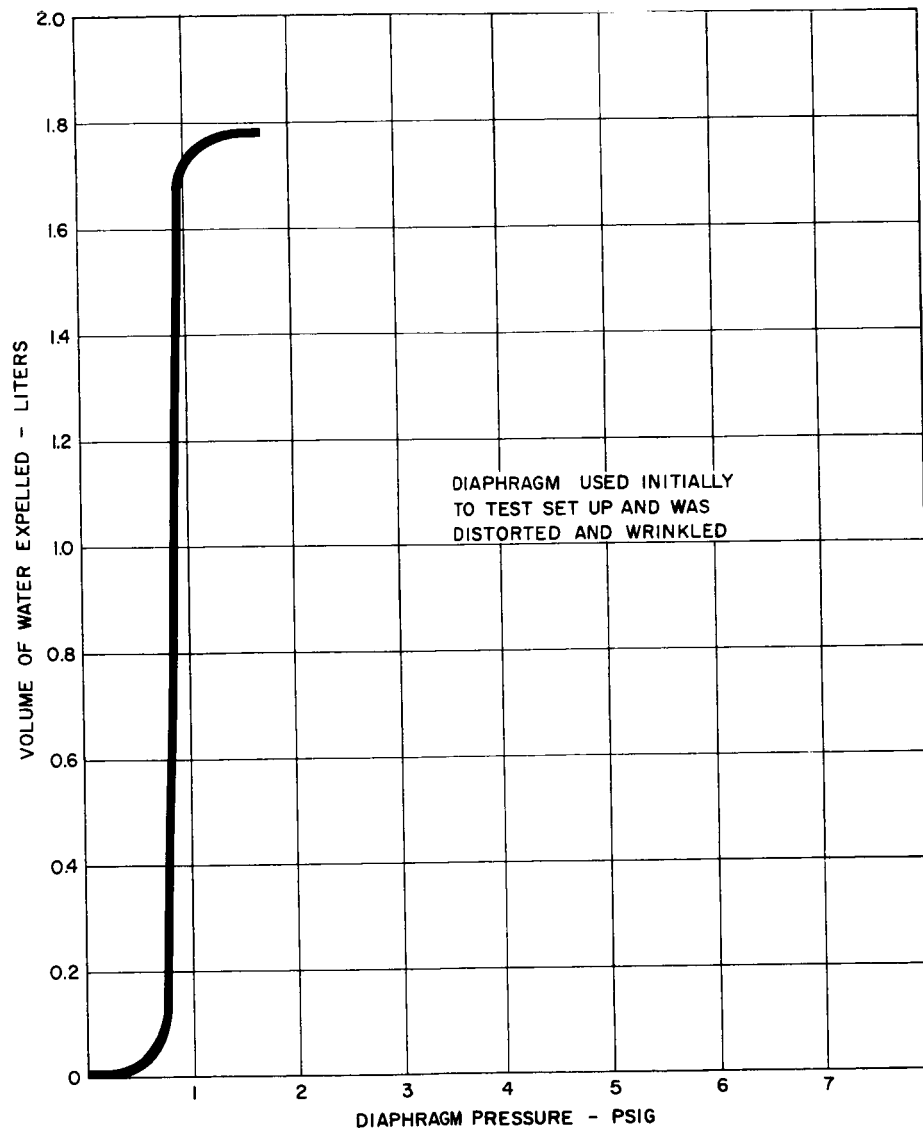


Figure 5. Liquid Expulsion versus Diaphragm Pressure
(Diaphragm No. 1)

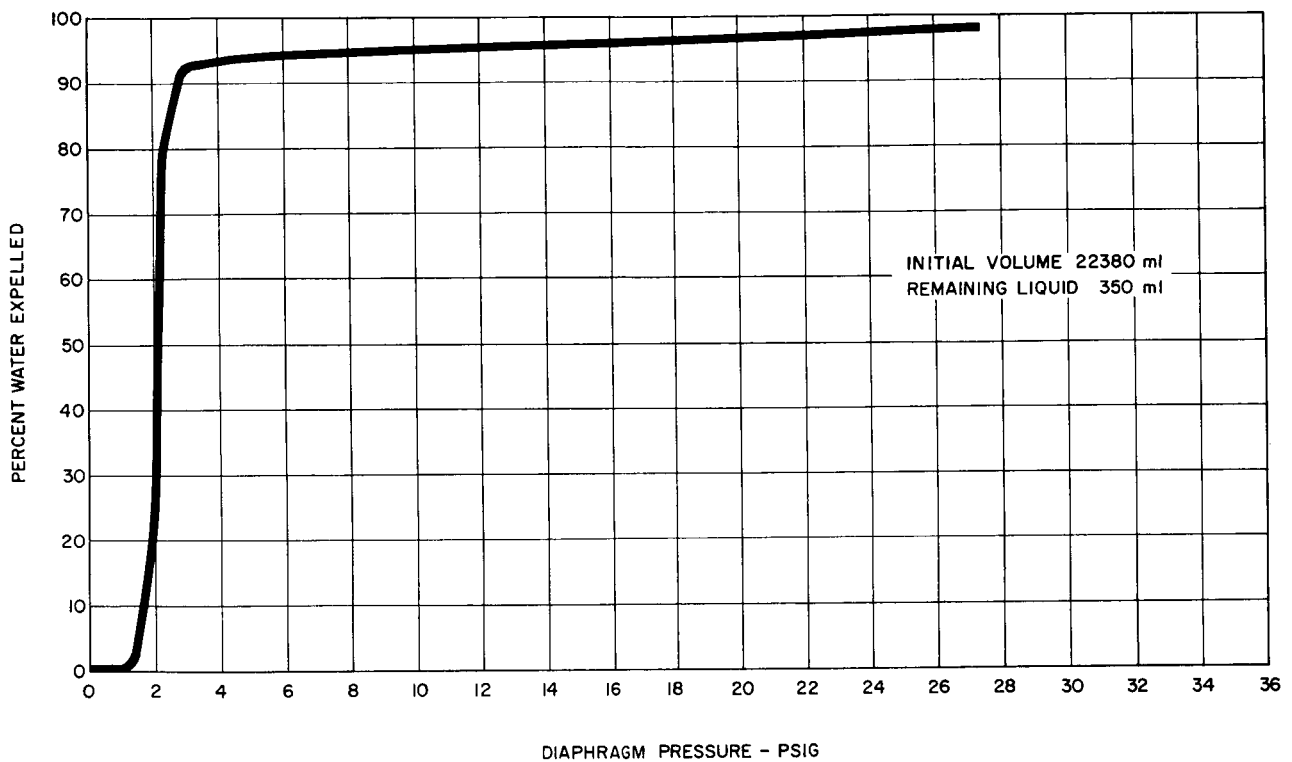


Figure 6. Liquid Expulsion versus Diaphragm Pressure
(Diaphragm No. 2)

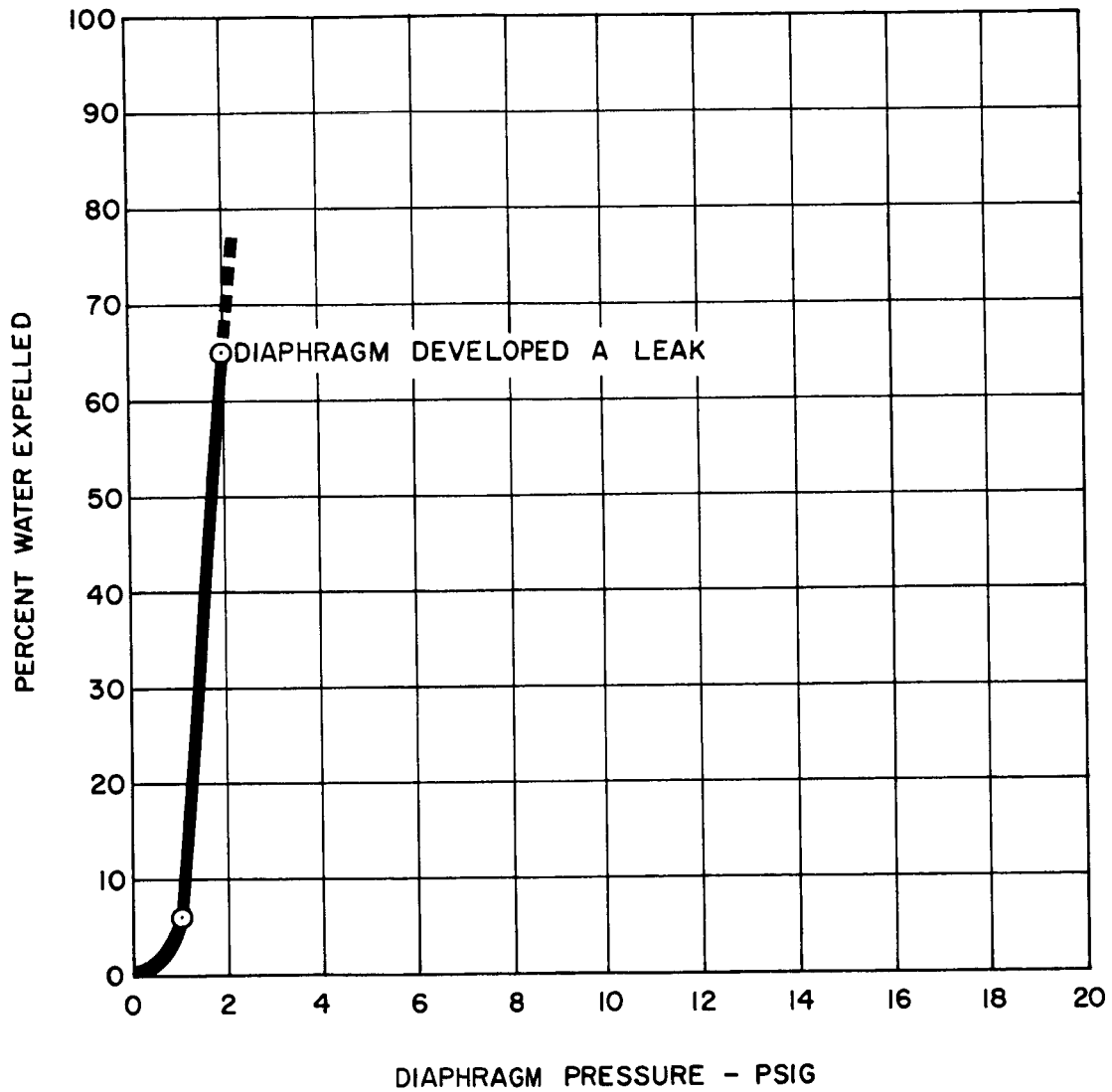


Figure 7. Liquid Expulsion versus Diaphragm Pressure
(Diaphragm No. 3)

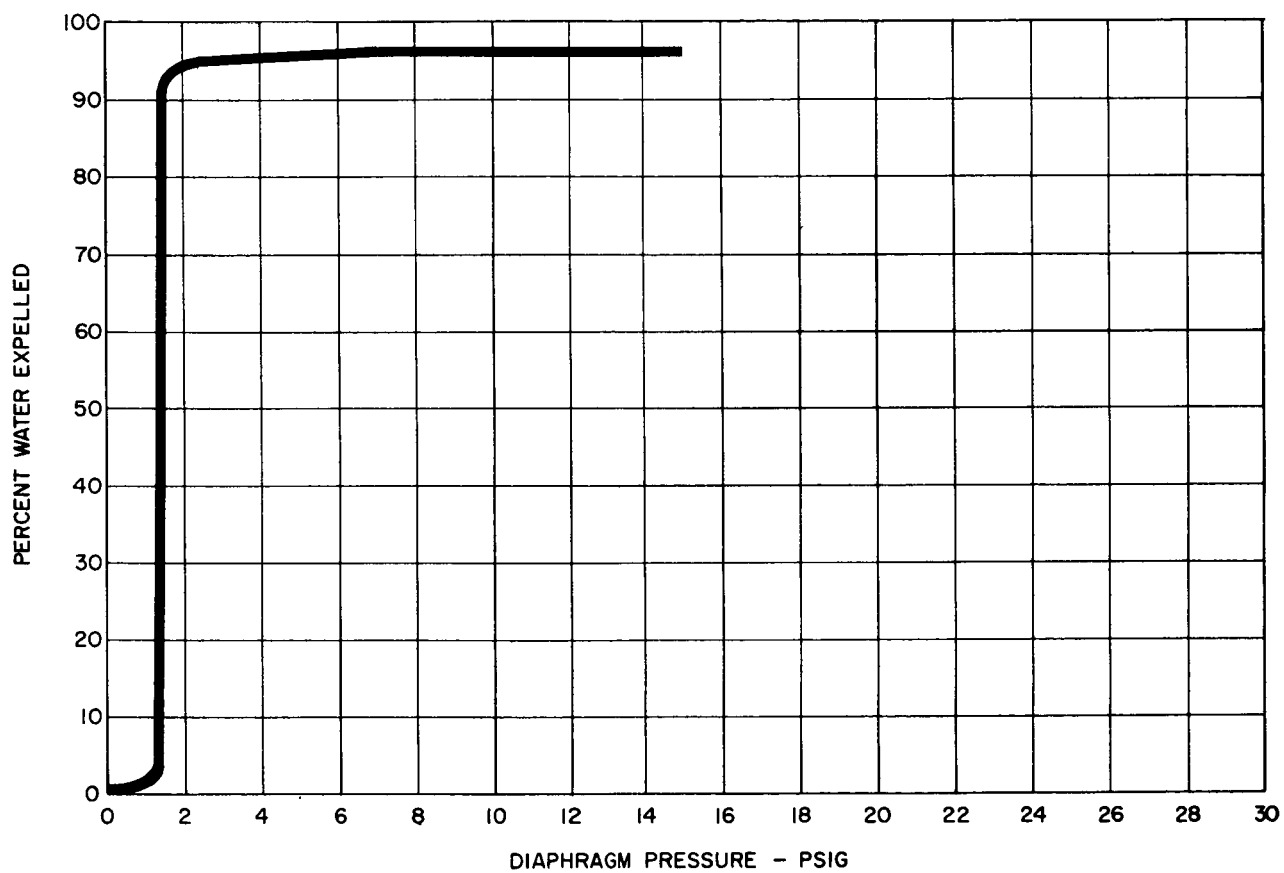


Figure 8. Liquid Explosion versus Diaphragm Pressure
(Diaphragm No. 4)

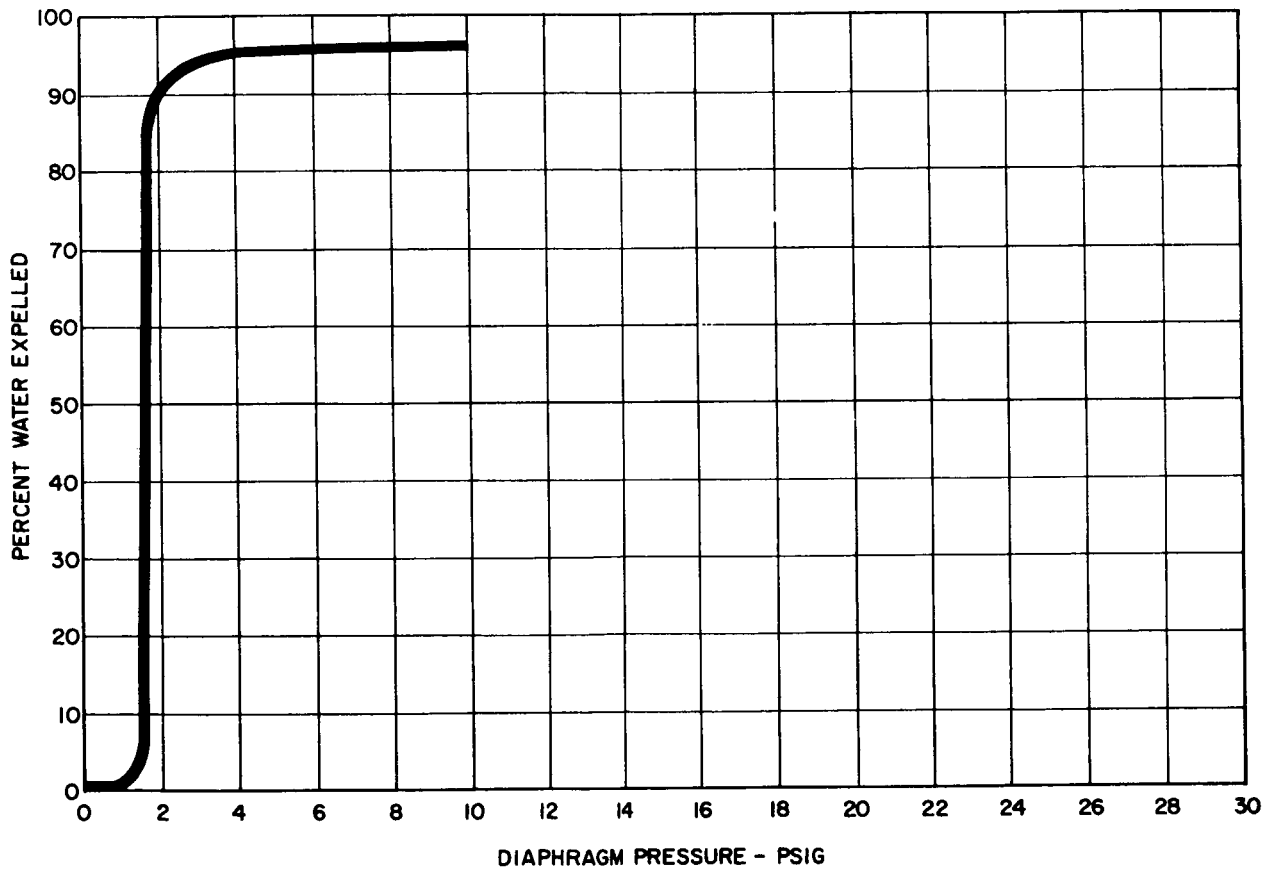


Figure 9. Liquid Explosion versus Diaphragm Pressure
(Diaphragm No. 5)

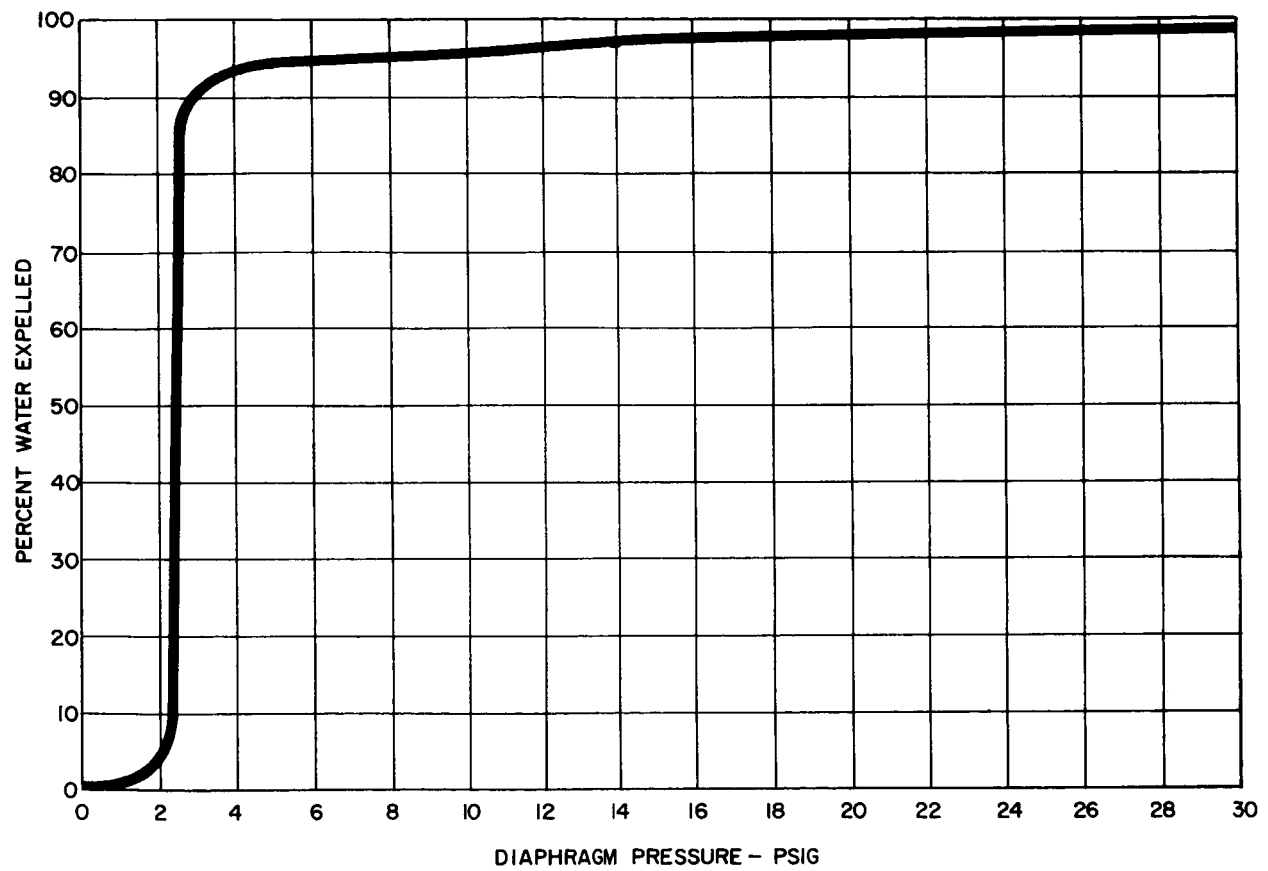


Figure 10. Liquid Explosion versus Diaphragm Pressure
(Diaphragm No. 8)

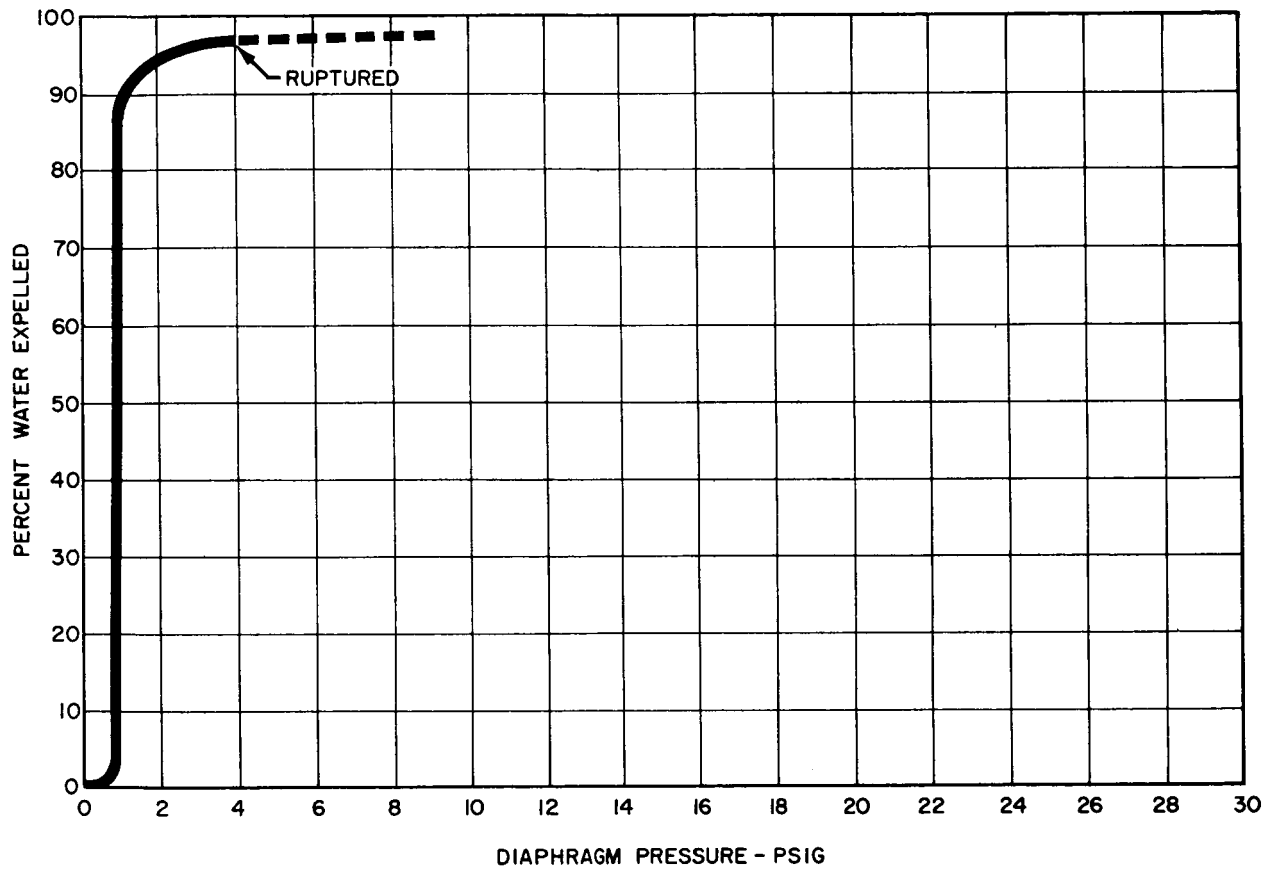


Figure 11. Liquid Explosion versus Diaphragm Pressure
(Diaphragm No. 9)

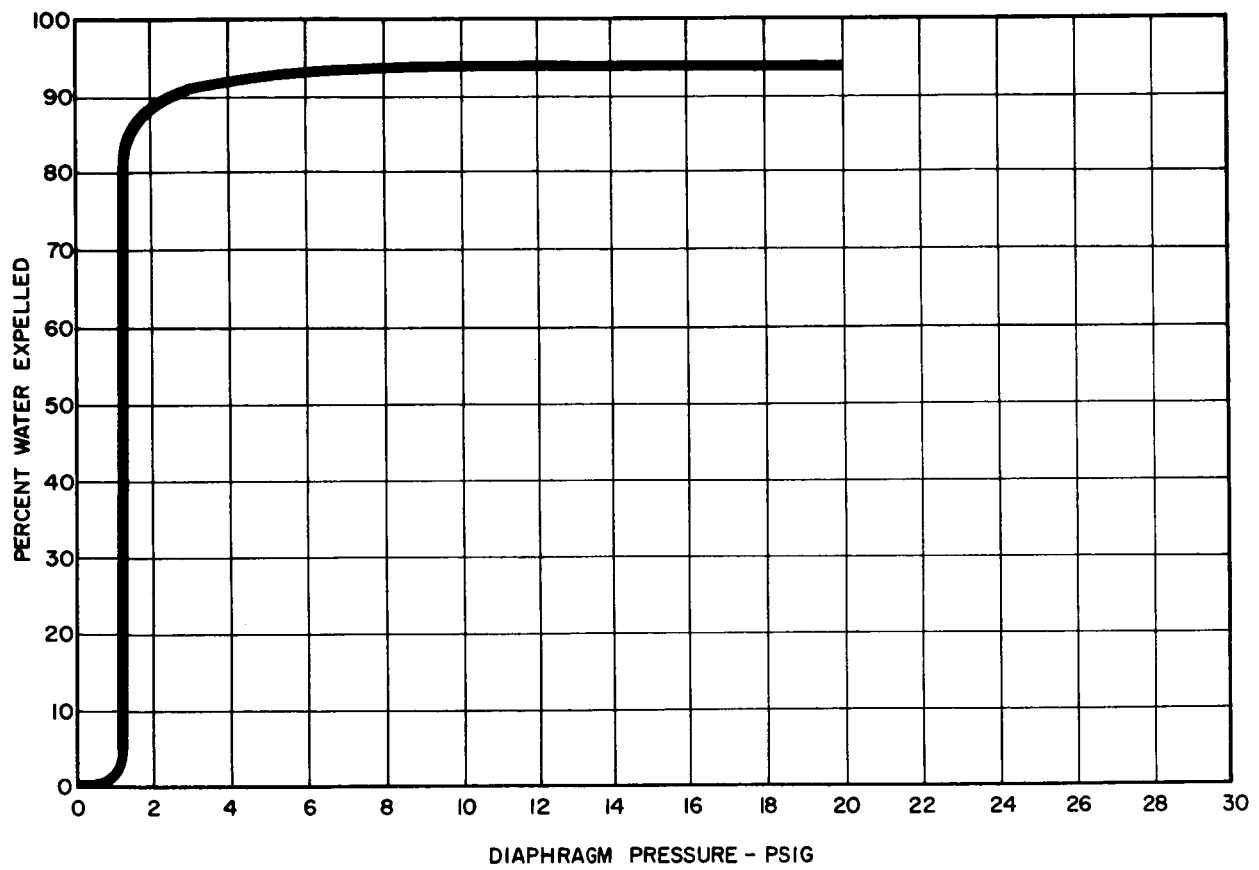


Figure 12. Liquid Explosion versus Diaphragm Pressure
(Diaphragm No. 10)

tears probably occurred due to non-uniform expulsion, (i. e., one side of the diaphragm rising before the other causing extremely sharp wrinkles). This non-uniform expulsion was noted in all tests, but it appears that the creases formed during tests 3 and 9 were more severe.

FUTURE DEVELOPMENTS

Two basic problems still remain to be solved:

1. Excessive working of the material during convoluting.
2. Reduction of pressure differential to achieve 98 to 99 per cent expulsion efficiency.

During fabrication of the present diaphragms, the material is required to make seven complete reversals causing moderate yielding and considerable work hardening of the unit. This requires that the material be annealed between various fabricational steps. This problem could possibly be reduced by any one of three methods:

- Convolution of the hemisphere by a spin-rolling form tool that starts its depression and forming of the hemisphere at the apex and progresses to the complete preform into the receiving die rings.
- Convolution of the hemisphere by depressing a preform convolute die ring down on the hemisphere near the major diameter to form the first large diameter convolute.
- Similar to the previous approach, except that a spring loaded wire or band is used to prevent the metal from bowing out or in, as the case may be, when approaching the sharp radius of the outside or largest convolution.

The problem of excess pressure differential (about 25 psi) to achieve 98 to 99 per cent expulsion efficiency is probably due to the fact that the energy is required to literally stretch the metal into the exact configuration of the tank. This problem may be solved by providing additional surface area on an expulsion unit beyond that required for the equivalent true surface. This "displaced radius" approach appears to permit the use of a heavier wall expulsion unit and thereby provides greater expulsion efficiency and rigidity, see Figure 13.

CONCLUSIONS AND RECOMMENDATIONS

During Honeywell's program, a method was developed for fabrication of large metal convoluted diaphragms. This approach required a combined air draw, explosive forming, and chemical milling to achieve the desired hemispherical size prior to convoluting. Ten units were subjected to expulsion test using water. Tests showed that 90 per cent expulsion efficiency could be obtained for units 0.010 or 0.015 inch thick, with less than three psi. However, over 20 psi was required to achieve 98 to 99 per cent efficiency.

Honeywell recommends that development to reduce this high differential be conducted possibly by the "displaced radius" technique.

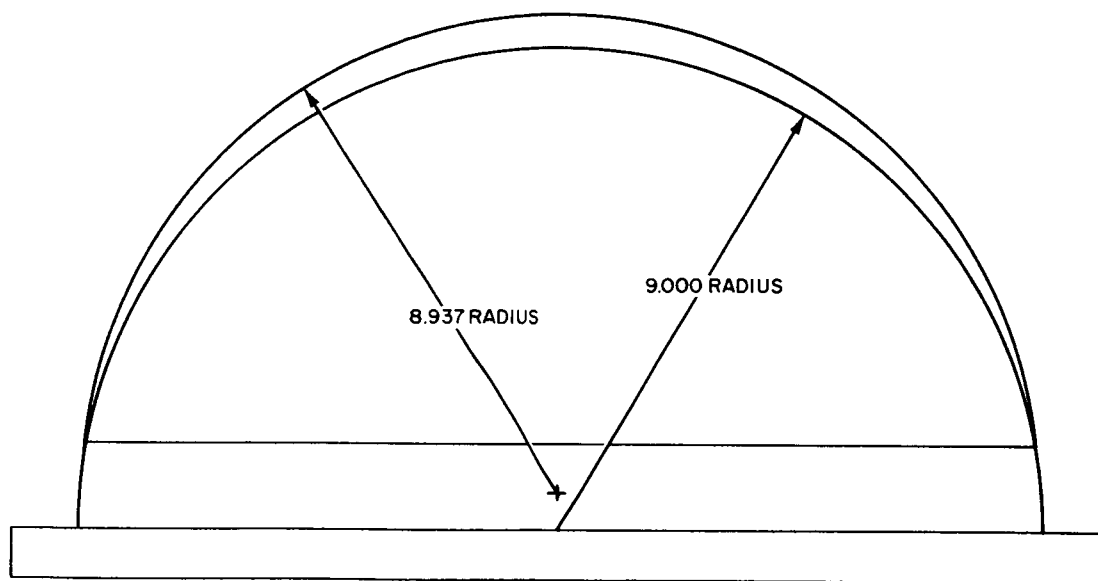


Figure 13. "Displaced Radius" Hemisphere for 18 inch Diameter Unit

APPENDIX A
WEEKLY PROGRAM LOG

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22 April to 28 April

Contract received and work commenced on the fabrication of punch and ring dies. Material study performed to determine types of aluminum which would prove suitable for use with hydrazine and nitrogen tetroxide. Aluminum 1100 and 6061 were ordered.

29 April to 5 May

Masonite male punch and ring dies completed. Equipment mounted on press for checkout. Material arrived and blanks cut to size. Test plan made and test equipment mounted.

6 May to 12 May

A blank of 1100-0 aluminum 0.020 inch thick was tried without oil bath. However, this proved unsuccessful. Press was then modified to include an oil bath. In this process, the punch drew the material through the ring die into an oil bath where pressure was controlled. This method was also unsuccessful.

13 May to 19 May

An "air draw" process was tried next. In this process, the material was clamped between the ring dies and a pressure plate. Air pressure was

induced over the material while a vacuum was drawn beneath. This method still produced rippling of the blank. Next an explosive forming method was tried, using only the ring dies and a bottom tank. However, reflected shock waves caused the process to fail. A female mold was then fabricated for use with both the air draw and explosive forming.

20 May to 26 May

Work on the fabrication of the female mold was started. Discussions were held with various metal working specialists to determine optimum fabrication methods.

27 May to 2 June

Work on the mold continued. The steel hold down plates for the mold were completed. A special "mill run" of aluminum was ordered for small grain size and uniformity.

3 June to 9 June

The female mold was completed and concrete cast for the mold backing. This work was done at the Twin Cities Arsenal.

10 June to 16 June

Exploratory forming and experimental modifications were made at the Twin Cities Arsenal. This work required that various type of charges and parameters be changed. The initial forming by the "air draw" process proved satisfactory.

17 June to 23 June

Exploratory investigation of trying to form the hemisphere from the flat stock by means of explosive forming was tried. Various parameters were changed without producing satisfactory results.

24 June to 30 June

Combination of "air draw" and explosive forming was tried. One hemisphere was formed but "orange peeling" of the surface occurred.

1 July to 7 July

Factory shut-down for two weeks. No explosive forming was done during this period. However, rework of the draw ring was started by model shop personnel not on vacation.

8 July to 14 July

Rework of draw ring was completed and some preliminary air drawing was done. It appeared that by reinforcing the center of the material, a hemisphere could be drawn to about 7 1/2 inches in depth. Using the same pressure but without the reinforcement, the material will only draw down to about four inches.

15 July to 21 July

Work on forming the hemisphere with a tape reinforcement was still under way. Some hemispheres were made using this technique. The method

appeared to greatly reduce "orange peeling" of the material. Mr. H. Stanford of JPL visited the fabrication facility during this week.

22 July to 28 July

More hemispheres were partially formed. Due to heat treatment furnace problems, very little was accomplished.

29 July to 4 August

Tapping of the blanks was found to be time consuming. It was decided that air draws with interior annealing would prove more economical. Twenty blanks were cut and the first units processed in this manner.

5 August to 11 August

Only 16 blanks were partially drawn successfully. Due to shut-down of the annealing furnace for repairs, some delays were experienced.

12 August to 18 August

It appeared that drawing could only be accomplished to a depth of five to six inches before stretching and rupture of the blanks. A meeting was held with various members of the project team concerning the fabrication process. It was decided to try a lamination process to support the center blank. This process would consist of a laminate of 0.030 - 0.010 - 0.020 inch blanks.

19 August to 25 August

The lamination process was tried without success; units still ruptured. Combinations of various thicknesses of aluminum were tried with only negative results.

26 August to 1 September

A laminate consisting of aluminum and a stainless steel sheet was tried with negative results. Also, other combinations were tried, including the use of certain lubricants, without success.

2 September to 8 September

A project team meeting was held. At this meeting an expert in chemical milling informed the group that it would be possible to chemically mill a thick (0.030 inch) aluminum hemisphere to the required thickness (0.010 inch) without encountering embrittlement of the material. A sample hemisphere was chemically milled and it was determined that 0.001 inch per minute of material could be removed. The project team also decided to use a teflon spray to coat the blanks to reduce draw friction. Preparations were made to conduct various tests.

9 September to 15 September

Using a polyethylene sheet instead of the teflon spray, which proved ineffective, a hemisphere of 0.030 inch thickness was drawn down to within one-eighth inch of the final shape. It was discovered that an "air draw"

process could be used as long as the process was done in a continuous manner. The almost completed hemispheres were then annealed and by means of explosive forming drawn down to the final dimensions. Then the units were chemically milled down to a thickness of between 0.01 to 0.015 inch.

16 September to 22 September

Using the units formed the previous week, several convolutions were attempted. However, it appeared that support rings were required for at least the first few convolutions. Work was started in making these support rings. Work also continued on the fabrication of more hemispheres. The diameter of the punch was reduced to facilitate convoluting.

23 September to 29 September

A crack in the draw ring above the mold was discovered. Fabrication of the hemispheres stopped during repair. Work on convoluting continued, but it appeared that support rings would be needed for almost all convolutions.

30 September to 6 October

Using the repaired draw ring, various draws were tried. Material appeared to be drawing from one side. Various hemispheres were convoluted and methods were tried to reduce rippling of the center convolution without success. However, a method to reduce the flange ripples proved very successful. This method consisted of taking an air drawn hemisphere and ironing the flange in a press, then explosively forming and chemical milling.

7 October to 13 October

More hemispheres were drawn and convoluted. To obtain all the convolutions, support rings had to be provided for each convolution. Work on the expulsion test set-up was started. The problem of the one sided draw was solved by controlling the friction during drawing.

14 October to 20 October

Using a hemisphere of 0.010 ± 0.002 inch thickness, an expulsion test was performed. The unit was first cycled so that 30 per cent of the volume was expelled and then drawn back. This, however, caused some serious wrinkles in the unit. A full expulsion test was performed next. When almost all the fluid had been expelled, cracks in the lower portion of the unit occurred, stopping the test.

21 October to 27 October

It appeared that wrinkles in the center section of the diaphragm could be ironed out without major difficulty. Two diaphragms were tested, both of 0.015 ± 0.002 inch thickness. Mr. Howard Stanford of JPL witnessed these tests.

28 October to 3 November

More expulsion tests were conducted during this week. Two units were subjected to an expulsion (in 30 seconds) without difficulty. Fabrication of more diaphragms continued.

4 November to 10 November

Diaphragm testing was completed and testing reports were prepared. Fabrication of units for JPL continued. No major problems were encountered.

11 November to 17 November

Fabrication of the hemispheres continued without major problems.

18 November to 24 November

Five units were completed and prepared for shipment to JPL. Fabrication continued on the balance of units.

25 November to 1 December

Shipment of five units was made to JPL and fabrication of the balance of the diaphragms was completed.

2 December to 8 December

Final 10 units were shipped to JPL. Final program report was completed. Program has been completed.